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# QUANTITATIVE STUDIES ON MARINE PHYTOPLANKTON AT LA JOLLA IN 1919

BY

WINFRED EMORY ALLEN

UNIVERSITY OF CALIFORNIA PUBLICATIONS IN ZOOLOGY
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WINFRED EMORY ALLEN

(Contribution from the Scripps Institution for Biological Research of the University of California)

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## INTRODUCTION

Beginning in 1901 and continuing from that time to the present under the active leadership of Dr. William E. Ritter, the San Diego Marine Biological Station, succeeded by the Scripps Institution for Biological Research of the University of California, has carried on varied and extensive investigation of oceanic phenomena. Under the pressure of explorational and other fundamental work little attention was given to the ecological study of phytoplankton until 1917, when the present writer was asked to develop the work along that line. The report covering preliminary operations of 1917 and 1918 has been published (Allen, 1921*a*); hence the present paper deals only with the work of 1919 after the beginning of standardized operations at the Scripps Institution.

Owing partly to shortage of equipment, no boat work was done by the Scripps Institution in 1919. As a consequence the collection of phytoplankton was limited to such work as could be done at the outer end of the pier, about 1000 feet from shore. Through the first eight months of the year daily hauls were made with a tow net. Efforts to make statistical studies of such material showed, however, that it was not very satisfactory for that purpose. Hence it became necessary to change the method of collecting which, after some experiment, was done on September 1, 1919.

The inadequacy of tow net catches was mainly due to the fact that at times in seasons of light production scarcely any phytoplankton was taken by a standard run of the net. Enumeration of such catches gave very little more information than was obtainable from casual inspection, i.e., that there was very light production of a very few forms. But tow net catches were also very unsatisfactory because it was impossible to say, even approximately, how much water had been traversed or filtered. Hauls were made over a measured distance but there was no way of knowing how strength and direction of currents, quantity of plankton, viscosity of the water, and abundance of sediment affected one catch as compared with another. For such reasons it was decided to preserve the tow net catches for qualitative reference and to confine quantitative studies to catches taken by the changed method. In this way the scope of this report is limited to the series of collections taken from the pier in the last four months of 1919.

## LOCATION

The Scripps Institution lies in approximately 32° 50′ north latitude and 117° 15′ west longitude. It is about two miles distant from the village of La Jolla, near San Diego, California. Other marine localities in about the same latitude are Charleston, South Carolina, the Bermuda Islands, the Madeira Islands, Alexandria (in Egypt), and Shanghai, China. Very little study has been made of either marine or fresh-water plankton in or near this latitude, and there is practically no other series of collections of phytoplankton fairly comparable with the one now under discussion. Hence it is necessary when comparing with other work to bear in mind the markedly different geographic conditions. The water temperature at the pier varies from about 13° C. in January to about 23° C. in August. Water at the outer end of the pier is about 27 feet deep at high tide.

## EQUIPMENT AND METHODS

I have in preceding papers (Allen, 1921 *b* and *c*) made brief statements concerning our standardized methods of collecting and handling material; those who desire more detailed information may obtain it by writing to The Director, Scripps Institution for Biological Research of the University of California, La Jolla, California.

## THE MATERIAL

Marine phytoplankton in temperate regions consists mainly and essentially of diatoms and dinoflagellates. The material obtained at our pier is typical in this respect. It is all microscopic.

### General Discussion

The regular series of catches at twelve hour intervals was begun at 8 A.M. on September 1, 1919. The new short net which was then put in use had been slightly shrunken and clogged by being used for making extra catches. In spite of this there was undoubtedly some loss of small forms through the meshes.

In most catches the living material consisted almost entirely of diatoms and dinoflagellates. There were times, however, when copepods, rotifers, and other very small animal forms were caught in considerable numbers. More rarely a few forms of various other kinds of microscopic plants were included.

According to a policy already determined after experience with phytoplankton from offshore waters, attention was confined to diatoms and dinoflagellates because their small size, large numbers, rapidity of growth, facility of multiplication, wide distribution, cosmopolitan character, and synthetic powers give them superior value as indicators of environmental conditions, mark them as the most favorable objects for quantitative study, and distinguish them as the most easily and continuously accessible of all marine organisms.

The distributional interrelationships of the two groups show many points of interest for which there are as yet no adequate grounds of discussion. This lack need not, however, invalidate tentative statements concerning them.

First, in making microscopic examination of the material I gained the impression that when diatoms were exceedingly abundant, dinoflagellates were rare, and vice versa. Hence I have earlier called attention to my belief in the possibility that the two groups are to some extent mutually exclusive of each other. It is still an open question whether this amounts to anything more than the commonly observed fact that excessive abundance of one group of organisms tends to reduce or exclude certain other groups. In fact, it is quite possible that many cases of apparent reduction of one under dominance of the other were merely apparent because dilutions for counting the abundant form rendered the other inconspicuous.

Both groups show rhythms and pulses of production which are more or less evident in each month of the year although, of course, the species concerned in the pulses vary according to season. It is rather difficult to define a pulse, but for present purposes I am arbitrarily assigning the term to a marked increase in numbers which extends over a period of three or more days before decreasing to or near the numbers found at its beginning. Of pulses in this arbitrary sense there were five for diatoms and four for dinoflagellates in the last four months of 1919 at our pier. The diatom pulses were unevenly distributed, two occurring in September, none in October, one in November, and two in December. The dinoflagellate pulses had similar distribution by months except that there was only one in

December. A diatom pulse at the middle of September was almost precisely coincident with a dinoflagellate pulse and there was partial coincidence of pulses of the two groups just after the middle of December. The fact that out of four chances for coincidence there were two close approximations to coincidence of pulses gives strong indication that both groups of organisms are often favored by the same stimuli to production, hence the idea that they may be mutually exclusive may seem unwarranted.

But an examination of the evidence from swarms shows other possibilities. A swarm may be arbitrarily defined for present purposes as a close aggregation of relatively large or even vast numbers of organisms of a certain group. Although what I have called a pulse may be (at least in some cases) due to the slow drift passing of an enormous swarm which occupies an area of several miles, I think we may confine present discussion to evidence of small swarms. This evidence consists merely in a conspicuous large catch found between much smaller catches, mostly less than one-third as large. Swarms identified in this way were, as might be generally expected, much more numerous than pulses in spite of the fact that nearness to shore made it probable that many swarms would be dispersed by the great disturbance in shallow waters. In the four months there were fourteen swarms of diatoms and fifteen swarms of dinoflagellates. Out of the fourteen chances for coincidence of swarms of the two groups only four actually occurred, a fact which might lead one to think the two groups somewhat deterrent to each other.

Not only does the evidence of pulses and swarms raise some interesting questions as to the interrelationship of the two great groups of synthetic organisms; it also has direct bearing on the perennial postulate that marine organisms are uniformly distributed through considerable areas of marine waters. The occurrence of pulses and swarms such as those just mentioned certainly tends strongly to contradict this assumption.

Further evidence tending to such contradiction appears in what, for lack of a better term, I may call skips. In the present connection a skip means a single strongly marked reduction in numbers in a way similar to that in which a strong increase is considered to indicate a swarm. In the four months, diatoms showed ten skips and dinoflagellates five, no two of which coincided. Surely a marked lack of organisms in a catch as compared with a catch twelve hours before and another twelve hours after gives good reason to suspect that

differences in distribution occur without appreciable difference in immediate environmental conditions.

Another point of interest concerns the relative amounts of morning and evening catches. In the following table, record is given merely of the number of times in the month that morning or evening catches were the larger. The results shown by this table have been checked up by a table showing the number of times in each month that a morning catch was higher or lower than both the evening catch preceding it and the evening catch following it, and by a similar table for evening catches. The substantial agreement in the three tables makes it fair to state that this table correctly indicates distribution in morning and evening catches.

Morning and Evening Maxima.*

| *Diatoms* | *Dinoflagellates* |
|---|---|
| September | September |
| Maxima at 8 A.M. 14 (5 catches near mean) | Maxima at 8 A.M. 12 (3 catches near mean) |
| Maxima at 8 P.M. 16 (4 catches near mean) | Maxima at 8 P.M. 18 (2 catches near mean) |
| October | October |
| Maxima at 8 A.M. 23 | Maxima at 8 A.M. 12 (1 catch near mean) |
| Maxima at 8 P.M. 8 (2 catches near mean) | Maxima at 8 P.M. 19 (2 catches near mean) |
| November | November |
| Maxima at 8 A.M. 24 (3 catches near mean) | Maxima at 8 A.M. 20 (3 catches near mean) |
| Maxima at 8 P.M. 6 | Maxima at 8 P.M. 10 (3 catches near mean) |
| December | December |
| Maxima at 8 A.M. 13 | Maxima at 8 A.M. 15 (5 catches near mean) |
| Maxima at 8 P.M. 18 (1 catch near mean) | Maxima at 8 P.M. 16 (1 catch near mean) |

It is very plain that no conclusions can be drawn from evidence so limited and contradictory, but it may be permissible to make suggestions. It seems strongly probable that there is a tendency to a diurnal rhythm in productivity, a rhythm which might be expected from what we know concerning fresh-water plants and land plants. If, according to such expectation, the phytoplankton is mainly active in photosynthesis by day and mainly active in growth and reproduction by night, we should get the results shown for diatoms in October and November, i.e., larger numbers in the morning catches.

Considering the multiplicity of factors involved, the large number of component species in the samples taken, and the variable speed and direction of water currents traversing the fixed point of collection, it is rather more surprising to find such a strong indication of rhythm

* I.e., one catch larger than the other. In a few cases the differences in numbers were very slight, but usually there was considerable difference at the two times of day.

than it is to find the neutral or contradictory evidence of the other two months. Even the reverse showing of the dinoflagellates is suggestive of diurnal rhythm in that group, although it is characteristically more erratic in distribution than the diatoms. At any rate the records suggest possibilities which are very interesting and which certainly open up a wide field for investigation.

In closing this general discussion of the material, I would remark that in the study of these two groups it was soon found that relatively few species showed marked prominence at any time, and that very few species had such prominence either frequently or continuously. Fortunately, most of these species can be satisfactorily identified under ordinary conditions of study.

A table giving the total numbers of phytoplankton cells per liter in all catches throughout the four months is given on pages 346–347.

## Detailed Discussion

### DIATOMS

Throughout most of the year and in most localities diatoms are both numerically and volumetrically the most prominent photosynthetic organisms in the open sea. The records for this four month period show characteristic conditions in this respect, November being the only month in which dinoflagellates appeared in superior numbers for the month as a whole.

Except for four catches in early September diatoms were always found to be present, though often in very small numbers. Since it is probable that larger samples would have revealed some in the four catches in which they were found lacking, it may be safely assumed that some diatoms might have been found at any time in the whole period.

Distribution of diatoms throughout the period was quite irregular, the most remarkable feature being very high productivity in the last three weeks of September following a season of extremely scant production and preceding a time of very light production. The accompanying graph (fig. 1) giving production in terms of averages of five day periods shows this condition with astonishing clearness. The areas filled in solid black indicate the relative size of average numbers found in each five day period.

In a general way the distribution agrees with that reported for the last four months of the year in other localities, both marine and

fresh water. It therefore seems certain that, considering the group as a whole, we have in this case a normal seasonal sequence. It is not so certain that the production of species or even genera involved follows any established course at least so far as has yet been detected or predicted.

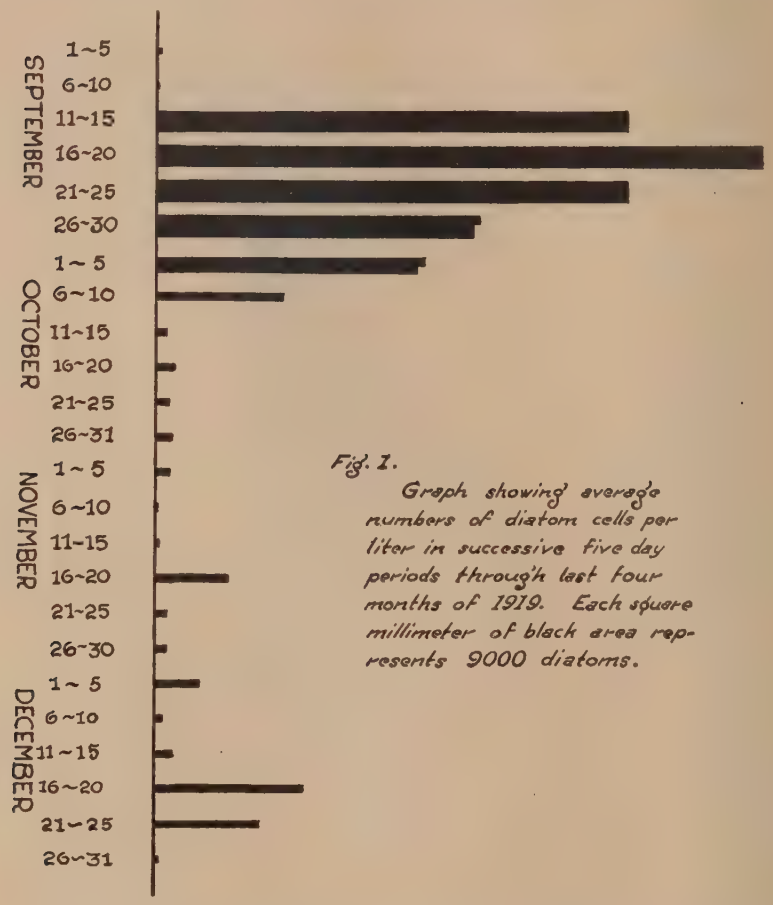


*Fig. 1.*
*Graph showing average numbers of diatom cells per liter in successive five day periods through last four months of 1919. Each square millimeter of black area represents 9000 diatoms.*

In connection with the high productivity so suddenly appearing in September, I was very much interested to note that for two or three days previously there had been rather strong and constant currents from the north. Also, large numbers of mackerel came to the region of our pier in the latter part of August and left as high production of diatoms began. Whether these facts were simply coincidences or whether they had significant relationship to increased diatom production I do not have means of knowing.

Although all other production was very inconspicuous as compared with the September maximum there was a pulse covering two days, November 17 and 18, at one time, and another covering six days, December 17–23, at another time. Since there was little current recorded at the November pulse its abrupt increase of some fifteen-fold may simply indicate the presence of a swarm stranded in quiet waters. While the December pulse at its highest showed about the same increase in production, its development was much less abrupt and so was its disappearance. In this case also the currents recorded were weak and the difference in development as compared with the November pulse might be considered due to relatively rapid production induced by some favorable local factor or favorable change in the factorial complex.

Forty-six forms of diatoms are listed as occurring within the four months in sufficient numbers to deserve separate mention. Of these only twelve had specific characters sufficiently marked to make identification easy. Fourteen could sometimes be satisfactorily identified and usually approximated, i.e., confusion was limited to only one or two other forms. Of the other twenty, some were always doubtful and others were simply grouped under the genus name because of small numbers or great uncertainty of identification.

The *Chaetoceras* genus offers most constant difficulties of this sort on account of its constant representation and on account of the fact that many species characters are based on conditions at sporulation or on terminal setae which may be missing. It is also true that many *Chaetoceras* chains are more or less twisted in form and that they lodge in all sorts of positions in the counting cell. Identification might be possible with unlimited time and effort, but it is not practicable to insure accuracy under counting conditions. Some *Chaetoceras* species could not be identified because of small size, as was also true of diatoms in other genera. In the main, however, the more important forms numerically in this series of catches were at least approximately identified as to species and almost all were correctly placed as to genus.

By selecting in each month the five species which showed the highest averages it is possible to get a good general idea of the character of the main diatom population throughout the four month period. Eleven forms are recorded in the highest five in one or more months. *Chaetoceras* sp. appears in this list in all four months, *Chaetoceras curvisetum* Cleve in three months, *Chaetoceras debile*

Cleve in three months, *Dactyliosolen tenuis* Cleve and *Nitzschia seriata* Cleve in two months, and the following in one month: *Chaetoceras decipiens* Cleve, *Chaetoceras didymum* Ehr., *Leptocylindrus danicus* Schütt, *Rhizosolenia alata* Btw., *Skeletonema costatum* Grev., and *Nitzschia pungens* Grun.

Certain forms which were originally recorded while counting have been omitted from the tables for one or more months because of small numbers or questionable identification. Their numbers have, however, been included in the total diatoms. These include *Amphiprora alata* Kütz., *Asterionella japonica* Cl., *Bacillaria paradoxa* Gmel., *Bacteriastrum varians* Laud., *Biddulphia longicruris* Grev., *Cerataulina bergonii* Perag., *Chaetoceras ralfsii* Cl., *Climacosphenia moniligera* Ehr., *Corethron criophilum* Castr., *Ditylium* sp., *Eucampia zoodiacus* Ehr., *Grammatophora marina* Lyngb., *Hemiaulus heibergii* Cl., *Lauderia borealis* Gran, *Leptocylindrus danicus* Cl., *Licmophora lyngbyei* Kütz., *Lithodesmium undulatum* Ehr., *Melosira* sp., *Nitzschia closterium* W. Sm., *Nitzschia* sp., *Rhizosolenia faeroensis* Ost., *Rhizosolenia hebetata* Bail., *Rhizosolenia obtusa* Hensen, *Rhizosolenia robusta* Norm., *Rhizosolenia setigera* Btw., *Rhizosolenia styliformis* Btw., *Stephanopyxis palmeriana* Grun., *Surirella* sp., *Thalassiosira baltica* Grun., *Thalassiothrix longissima* Cl.-Gr., and *Thalassiothrix nitzschiodes* Grun.

For similar reasons a number of species originally listed have been grouped together in their genera or under a loosely applied species name. This is especially true of some forms in *Chaetoceras, Biddulphia, Coscinodiscus,* and *Rhizosolenia* genera.

Gran's paper (1908) has been most helpful in identifications.

## SPECIES OF DIATOMS

For economy of space I shall confine discussion mainly to the eleven species represented in the lists of the five species most abundant in one or more months. These are distributed unequally among six genera listed in alphabetical order as follows:

*Chaetoceras.*—This genus had relatively high numerical representation in every month. It was responsible for the high records of production in September, when several species far outnumbered representatives of any other genus. No large *Chaetoceras* forms were present and some were very small. Even so, the genus appears to be more productive than other diatom genera in volume as well as in

numbers. Roughly, it may be said to be the most important genus of planktonic diatoms.

*Chaetoceras curvisetum* Cl.—Frequently confused in our records with *Ch. debile* Cl. I have not found any satisfactory way to distinguish the two forms while counting. When possible, segregation has been made according to Gran's (1908) suggestion that interspaces between the cells are biconvex in *Ch. curvisetum* and rectangular in *Ch. debile*. Sometimes one and sometimes the other is very abundant and both are very commonly found in our waters. Segregation is attempted merely because the records, though imperfect, may sometime show some value.

In September the species reached a maximum of 276,000 per liter at 8 P.M. on the 14th. It was missing entirely from many catches before the 11th but showed a very strong and even development of production after that date until the maximum was passed, when the numbers gradually decreased. Average production for the month was 32,089 per liter. These numbers refer to cells. On account of curvature of the chain of cells exact enumeration was often impossible but the approximation is usually close. This species was frequently missing in catches in the other three months and it is quite evident that its abundance in September was due to a favorable combination of environmental factors.

*Chaetoceras debile* Cl. has a record of distribution and of appearance markedly similar to that of *Ch. curvisetum* Cl., and there is little to say about it at present. Maximum production of 81,000 per liter was reached at 8 P.M. on September 17.

*Chaetoceras decipiens* Cl. was not always clearly identified. Shape of cells and of interspaces varied greatly and the typical form was rarely seen. Basal fusion of the setae was the characteristic relied upon for recognition and even it was sometimes questionable. Numerous gradations between the typical form and some which were otherwise scarcely recognizable were often found on the same slide. Representation in September as well as in other months was rather irregular, the maximum, 27,200, being reached on September 26 at 8 P.M. in a poorly developed three day pulse. *Ch. decipiens* was entirely missing through two-thirds of October and a large part of November. When present in the last three months of the year representation was light.

*Chaetoceras didymum* Ehr. was never very prominent in any catches, although its identity was probably often overlooked. Its

characteristics are somewhat variable, especially as to general appearance of the chain and of the setae. It was probably confused sometimes with *Ch. constrictum* Gran and some other forms. Its maximum was reached on September 16 at 8 A.M. in a catch numbering 14,800, the average for the month being 1674. It is not recorded after the middle of October.

*Chaetoceras* sp. is a catchall for a large number of species difficult to identify, or rare. In the four months under consideration its main components were small forms with poorly marked characters, of which *Ch. affine* Laud. was probably most prominent. Numerically and probably volumetrically this assemblage was distinctly the most important of the diatoms in September, October, and December. The maximum, 339,376, was recorded for September 24, 8 P.M., and there was an average for that month of 90,069 per liter. High production of this group began about September 11 and lasted almost a month. Its numbers in the catches then became very small until the latter part of November. While not very abundant, considerable numbers were found through most of December.

*Dactyliosolen* was represented apparently by only one species, *D. tenuis* Cl., and identification in many cases was not very certain. It was fairly well represented in October and November, but very slightly in the other two months. Maximum, 5700 per liter, October 21, 8 A.M., average in October, 1464.

*Leptocylindrus* also showed only one species, *Leptocylindrus danicus* Schütt. This form attained considerable prominence in late September and early October, but was almost or quite absent at other times. Maximum production, 17,600, was reached on October 6 at 8 A.M. and the average in October was 2187. This form does not appear to be of great importance in our region.

The genus *Nitzschia* was probably represented by several species but only two attained much numerical importance, *N. seriata* Cl. and *N. pungens* Grun. Their distribution as recorded was essentially similar and there were very many cases in which it was uncertain whether the specimen was rightly called *N. pungens* or whether it was merely a small specimen of *N. seriata*. Such cases, together with the similarity in distribution, lead one to think that perhaps the two forms may both be properly included under *N. seriata*. There is, however, some advantage in keeping the records separate, since a marked and fairly consistent deviation within the species may help to show the influence of certain environmental factors, such as temperature in relation to growth, shape, etc.

*Nitzschia seriata* Cl. is a very prominent diatom in this region. It may be found at any time of year though surface catches indicate that it is typically a winter or spring form. It has been found in large numbers in July and August in vertical tow net catches taken from two hundred meters to surface near Santa Cruz Island and in one or two other localities. This fact leads to the supposition that this as well as other forms of the phytoplankton may flourish at the surface in one season and at a lower level in another season. The largest catch of *N. seriata* in the four months was on December 22 at 8 P.M. The number was 5900 per liter and the average for the month was 830. The maximum occurred in a well developed pulse which began on December 15 and ran ten days.

As already stated, *N. pungens* is often not readily distinguishable from *N. seriata*. Its occurrence in December was coincident with the latter in a pulse that ran the same course. The maximum was reached at 8 A.M. on December 20 in a catch of 7700 per liter and the average for the month was 831.

The genus *Skeletonema* is represented in our catches by only one species, *Skeletonema costatum* Grev. Its numbers were few in September and it was missing in October. Occurrence in November was very irregular, although it was conspicuous in a few catches just after the middle of the month. In December it appeared more regularly in the catches and reached a maximum of 4160 per liter on the 19th at 8 A.M. The average for December catches was 919 per liter. *S. costatum* is frequently found in our region and is probably an important general constituent of our phytoplankton.

No other genera of diatoms reached much importance in the four months and there does not seem to be anything in records of their occurrence which is not in essential agreement with those of the genera just discussed. Evidently any peculiar significance which they may have can only be determined by careful statistical analysis.

One point, however, is clearly shown by detailed studies, i.e., that when there is a pulse of the highly productive forms there is also a pulse or marked increase in numbers of those forms of lower production and there is also an increase in the number of species and of genera represented. This also seems to be true to a lesser extent of swarms. Such facts naturally lead to the assumption that in a general way ecological conditions in the sea favorable to high production of diatoms affect a large number of forms in the same way.

## DINOFLAGELLATES

Although some dinoflagellates are nearly always present in plankton catches taken in the San Diego region, they are often very few, and they are rarely so numerous as diatoms. This deficiency in numbers is compensated to some extent by the fact that many prominent dinoflagellates are larger than any planktonic diatom cells and also by the fact that living substance constitutes a larger part of the cell body in dinoflagellates than it does in diatoms. But even when we accept the statement made by Johnstone (1908, p. 192) that one peridinian contains as much dry matter as twelve diatoms, it still appears that dinoflagellate production over long periods of time is distinctly less than diatom production, volumetrically as well as numerically. As to the four months now under discussion, however, we may note that although dinoflagellates were found in distinctly greater numbers than diatoms only in November, in October and December their numbers were one-eighth and one-fourth as great, respectively, as those of diatoms, which according to the ratio mentioned by Johnstone would indicate that they were volumetrically more important than diatoms in three months out of the four.

At least a few dinoflagellates were present in every catch made at this time. Their distribution was somewhat irregular though not so markedly so as that of the diatoms. The extremes were not so great and the representation was more constant in spite of the generally smaller numbers. This, however, was offset to some extent by the more frequent and sudden changes in numbers (fig. 2). In figure 2 the areas filled in solid black indicate the relative average numbers found in each five day period (including ten catches), except in October and December where the last period consists of six days with twelve catches.

The general features of distribution in the four months seem to be essentially similar to those of distribution reported for other localities. As in the case of the large diatom pulse in September, the largest dinoflagellate pulse, which came in November, was preceded for a day or two by strong currents of water from the north and was also accompanied by moderate currents from that direction. While it is not probable that these currents flowed continuously in the one direction, it is probable that the main shift of the water mass was that way. A successful recording apparatus for water currents was put in operation at one time by our hydrographer, Dr. G. F. McEwen, but

no means was found to protect it from rough seas and it was only in operation for a short time. For that reason records of currents are made from observations at times of taking catches.

Thirty-seven forms of dinoflagellates are listed as occurring within the four months in sufficient numbers to deserve separate mention.

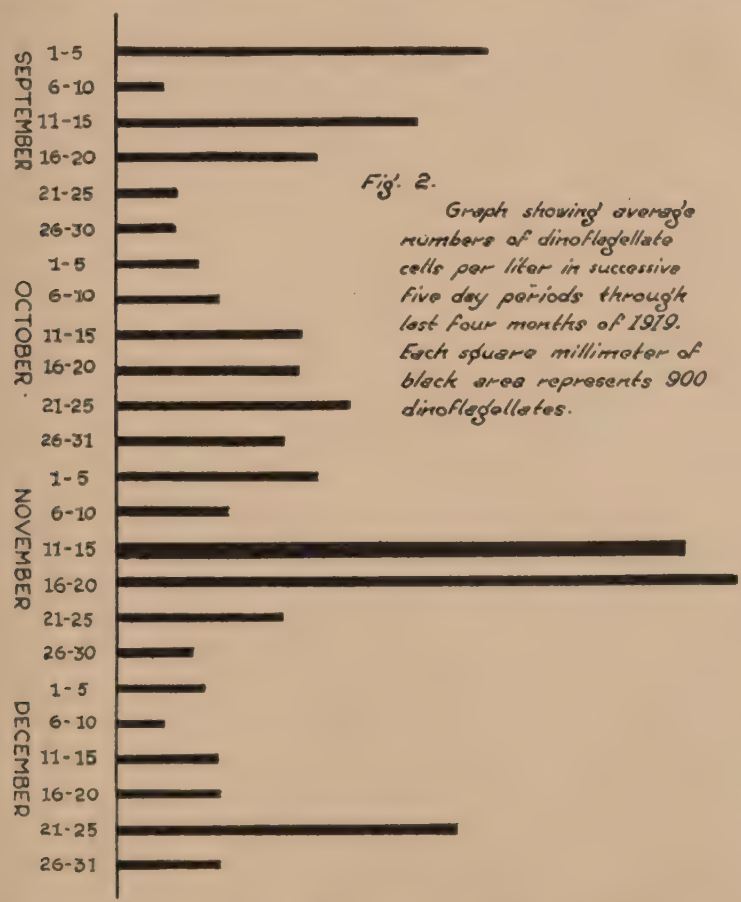


*Fig. 2. Graph showing average numbers of dinoflagellate cells per liter in successive five day periods through last four months of 1919. Each square millimeter of black area represents 900 dinoflagellates.*

Of these only eight had specific characters sufficiently well marked to make identification easy. Twelve forms could be sometimes satisfactorily identified and usually approximated, i.e., confusion was limited to only one or two other forms. Of the other twenty-five, some were always doubtful and a few were simply grouped under the genus name because of small numbers or uncertainty of identification. There was more or less difficulty in identifying species in all genera.

There was not often any difficulty in identifying the genus to which a specimen belonged. Identification was usually fairly satisfactory in case of the forms which appeared to be numerically important. Certain errors in identification of species on account of the position of the specimen in the counting cell were no doubt frequent.

As in the case of diatoms it seems possible to get a fair general idea of the dinoflagellate population in a month by selecting the five showing higher numerical averages for the month. In a list thus selected four species appear throughout the four months, *Ceratium furca* (Ehr.), *Dinophysis homunculus* Stein, *Gonyaulax polyedra* Stein, and *Prorocentrum micans* Ehr.; all are, in most cases, easily identified. Of the two other species listed in the first five, *Ceratium fusus* (Ehr.) appears in three months and *Peridinium divergens* Ehr. in one.

Certain forms which were originally recorded while counting have been omitted from our final tables for one or more months because of small numbers or questionable identification. Their numbers have, however, been included in the total dinoflagellates. The names are *Ceratium arcticum* (Ehr.), *Ceratium breve* (Ost. & Sch.), *Ceratium gallicum* Kof., *Ceratium macroceros* (Ehr.), *Ceratium pennatum* Kof., *Ceratium pentagonum* Gour., *Ceratium tripos* (O. F. M.), *Dinophysis acuta* Ehr., *Dinophysis hastata* Stein, *Dinophysis ovata* Clap. & Lachm., *Gymnodinium* sp., *Noctiluca miliaris* Surir., *Oxytoxum scolopax* Stein, *Phalacroma rudgei* Murr. & Whitt., *Phalacroma rapa* Stein, *Peridinium grani* Ostf., *Peridinium pellucidum* (Bergh), and *Pyrocystis lunula* Schütt.

A number of species originally listed have been grouped together in their genera or under a loosely applied species name for similar reasons. This is especially true of some forms in *Ceratium, Dinophysis, Gonyaulax,* and *Peridinium.*

Paulsen's paper (1908) has been most useful in identifications.

For economy of space, detailed discussion of species of dinoflagellates is omitted from this paper. Kofoid's careful studies (Kofoid, 1907 *a* and *b* and 1911) have given much more knowledge of the members of this group than is the case with diatoms.

## CONCLUSION

Since the work of 1920 and 1921 has been a direct extension and expansion of the work in 1919 it is scarcely desirable or appropriate to attempt to state very much in the way of general conclusions in this immediate connection. Such a statement can be more satisfactorily attempted after study of the records for one or more years.

Meanwhile, however, one or two points may be noted to advantage:

First, the measured water method seems to be by far the best for a *standard* method and the surface level the best for a *standard* level of collecting. At the time of this writing, May 26, 1921, we have given a continuous trial to this plan of procedure over a period of twenty-one months at our pier and fifteen months at another. In addition we have used it on various boats and now have it in operation at three other piers. From such experience we are convinced that it is the only method affording an adequate basis for expansive quantitative work on the phytoplankton as distinguished from the elementary, superficial work permitted by any tow or haul net method.

Second, it appears probable that water currents have very pronounced influence on phytoplankton production.

Third, when conditions for production are highly favorable in our area, there is evident response by large numbers of phytoplankton organisms frequently of both dinoflagellates and diatoms.

Fourth, conditions of occurrence suggest the probability that certain common forms of wide distribution, such as *Nitzschia seriata* Cl. and *Prorocentrum micans* Ehr., may serve well as indicators of certain general conditions of the ecologic complex while some less abundant forms, such as *Asterionella japonica* Cl. and *Dinophysis homunculus* Stein, may prove to be excellent indicators of more specific conditions in the ecologic complex.

Lastly, it is evident that the problems of the ecologic complex of the sea are fascinating as well as intricate and baffling; e.g., was the big diatom pulse in September due merely to the transfer into our area of a seed bed of diatoms which had developed farther north? Or was it due to removal of predatory copepods by the small fish which the mackerel chased in? Or was it due to the high increase in carbon dioxide and nitrogenous materials resulting from the presence and activity of unusual quantities of fish? Or was it due to a combination of all these, with a thousand other influences, the resultant of all of which was good?

TOTALS OF PHYTOPLANKTON. NUMBER CELLS PER LITER

Pier series. 8 A.M. and 8 P.M. September to December, inc., 1919

Scripps Institution for Biological Research, University of California

| Date | Hour | September | October | November | December |
|---|---|---|---|---|---|
| 1. | 8 A.M. | 5,522 | 214,480 | 4,036 | 5,616 |
| | 8 P.M. | 1,148 | 154,352 | 6,960 | 5,644 |
| 2. | 8 A.M. | 6,614 | 74,624 | 5,092 | 6,236 |
| | 8 P.M. | 3,288 | 59,872 | 3,344 | 14,416 |
| 3. | 8 A.M. | 4,628 | 48,624 | 10,344 | 11,520 |
| | 8 P.M. | 6,216 | 56,936 | 4,160 | 18,192 |
| 4. | 8 A.M. | 16,444 | 45,480 | 8,216 | 9,504 |
| | 8 P.M. | 6,096 | 32,712 | 3,012 | 800 |
| 5. | 8 A.M. | 6,904 | 27,726 | 2,548 | 1,824 |
| | 8 P.M. | 1,804 | 51,504 | 1,224 | 2,076 |
| 6. | 8 A.M. | 480 | 33,200 | 1,796 | 2,364 |
| | 8 P.M. | 276 | 48,008 | 1,264 | 3,488 |
| 7. | 8 A.M. | 172 | 26,800 | 1,224 | 1,492 |
| | 8 P.M. | 392 | 28,904 | 952 | 1,732 |
| 8. | 8 A.M. | 360 | 26,640 | 1,148 | 868 |
| | 8 P.M. | 1,048 | 10,608 | 784 | 1,856 |
| 9. | 8 A.M. | 864 | 7,288 | 1,868 | 1,184 |
| | 8 P.M. | 1,718 | 5,944 | 2,640 | 1,496 |
| 10. | 8 A.M. | 1,402 | 5,280 | 3,236 | 2,008 |
| | 8 P.M. | 1,348 | 3,040 | 4,080 | 772 |
| 11. | 8 A.M. | 4,380 | 6,160 | 7,860 | 1,760 |
| | 8 P.M. | 15,608 | 8,084 | 16,856 | 1,720 |
| 12. | 8 A.M. | 105,328 | 6,928 | 11,952 | 2,304 |
| | 8 P.M. | 58,392 | 6,424 | 6,484 | 936 |
| 13. | 8 A.M. | 135,904 | 2,184 | 37,816 | 1,348 |
| | 8 P.M. | 169,296 | 1,868 | 29,736 | 780 |
| 14. | 8 A.M. | 279,376 | 1,532 | 27,728 | 2,816 |
| | 8 P.M. | 367,232 | 2,956 | 9,692 | 6,808 |
| 15. | 8 A.M. | 450,912 | 1,872 | 9,428 | 13,312 |
| | 8 P.M. | 471,104 | 3,080 | 8,680 | 7,668 |
| 16. | 8 A.M. | 279,160 | 2,708 | 8,620 | 6,228 |
| | 8 P.M. | 348,640 | 4,864 | 5,040 | 8,216 |
| 17. | 8 A.M. | 384,960 | 5,180 | 33,372 | 11,484 |
| | 8 P.M. | 485,240 | 1,872 | 43,376 | 16,684 |
| 18. | 8 A.M. | 333,120 | 7,908 | 56,116 | 18,620 |
| | 8 P.M. | 183,440 | 7,000 | 11,744 | 23,904 |
| 19. | 8 A.M. | 129,920 | 5,340 | 17,164 | 23,460 |
| | 8 P.M. | 200,280 | 6,232 | 3,592 | 34,180 |
| 20. | 8 A.M. | 103,584 | 8,468 | 4,712 | 45,572 |
| | 8 P.M. | 161,280 | 3,192 | 7,756 | 36,512 |
| 21. | 8 A.M. | 153,888 | 8,852 | 8,360 | 25,976 |
| | 8 P.M. | 96,960 | 1,796 | 2,700 | 34,836 |
| 22. | 8 A.M. | 174,832 | 6,616 | 2,450 | 24,944 |
| | 8 P.M. | 196,592 | 2,088 | 4,160 | 32,304 |
| 23. | 8 A.M. | 104,528 | 15,496 | 4,424 | 17,172 |
| | 8 P.M. | 260,464 | 2,244 | 2,216 | 14,284 |

TOTALS OF PHYTOPLANKTON. NUMBER CELLS PER LITER—(*Continued*)

| Date | Hour | September | October | November | December |
|---|---|---|---|---|---|
| 24. | 8 A.M. | 185,312 | 6,140 | 6,304 | 14,412 |
| | 8 P.M. | 340,784 | 2,136 | 6,292 | 16,824 |
| 25. | 8 A.M. | 270,448 | 3,380 | 1,344 | 5,764 |
| | 8 P.M. | 233,888 | 4,140 | 1,980 | 10,352 |
| 26. | 8 A.M. | 132,928 | 5,340 | 1,876 | 3,088 |
| | 8 P.M. | 130,624 | 3,228 | 2,952 | 3,464 |
| 27. | 8 A.M. | 265,024 | 5,828 | 1,528 | 3,680 |
| | 8 P.M. | 160,400 | 3,232 | 2,208 | 1,520 |
| 28. | 8 A.M. | 115,904 | 3,396 | 2,184 | 3,136 |
| | 8 P.M. | 49,664 | 3,808 | 1,312 | 3,016 |
| 29. | 8 A.M. | 65,408 | 10,504 | 2,984 | 824 |
| | 8 P.M. | 89,792 | 5,192 | 1,976 | 1,624 |
| 30. | 8 A.M. | 254,224 | 4,624 | 6,528 | 1,160 |
| | 8 P.M. | 103,904 | 3,128 | 3,432 | 744 |
| 31. | 8 A.M. | ..... | 3,720 | ..... | 744 |
| | 8 P.M. | ..... | 4,208 | ..... | 568 |

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